

HUMAN CATHELICIDIN ANTIMICROBIAL PEPTIDES

STATEMENT AS TO FEDERALLY SPONSORED RESEARCH

[0001] The U.S. Government has certain rights in this disclosure pursuant to Grant Nos. AR41256 and AI052453 awarded by the National Institutes of Health.

CROSS REFERENCE TO RELATED APPLICATIONS

[0002] This application claims priority under 35 U.S.C. §119 from Provisional Application Serial No. 60/512,953, filed October 21, 2003, the disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

[0003] The disclosure relates peptides and methods to treat viral and other microbial infections.

BACKGROUND

[0004] Small, cationic antimicrobial peptides (AMPs) are naturally occurring antibiotics of the innate immune system. AMPs are widely distributed in animals and plants and are among the most ancient host defense factors. Their spectrum of activity includes Gram-positive and Gram-negative bacteria as well as fungi and certain viruses. As resistance of pathogenic microbes to conventional antibiotics increases, researchers are exploring these endogenous antibiotics as a potential source or new therapies against variety of infectious diseases.

[0005] Virus infections occur following entrance of virions into host cells by a variety of mechanisms including endocytosis of non-enveloped viruses and fusion with the cell membrane by enveloped viruses. One primary barrier to the infection is epithelial keratinocyte of the skin. Alterations in skin barrier function are seen in atopic dermatitis (AD). This finding may contribute to infection with bacteria and selected viruses, including Herpesviridae (herpes simplex virus (HSV), varicella-zoster virus) and vaccinia virus.

However, it is unlikely that a defect in the physical barrier alone accounts for the remarkably increased susceptibility of AD patients to recurrent skin infections. Patients with plaque psoriasis, a common Th1-mediated inflammatory skin disease also associated with skin barrier dysfunction, do not have increased susceptibility to microbial skin infection.

SUMMARY

[0006] The invention provides a method for inhibiting the spread and/or reducing the risk of infection of a virus comprising contacting a virus with an inhibiting effective amount of a cathelicidin functional fragment. In one aspect the cathelicidin functional fragment comprises a peptide that is 16-36 amino acids in length; and contains the sequence NH₂-X₁X₂X₃X₄X₅X₆IKX₇FX₈X₉X₁₀LX₁₁P-COOH (SEQ ID NO:1), wherein X₁, X₂, and X₆ are individually K or R; wherein X₃ is I or K; wherein X₄ is V or G; wherein X₅ is Q or R; wherein X₇, X₉, X₁₀, and X₁₁ are each individually any amino acid; and wherein X₈ is L or F. In a further aspect, the peptide is about 16 to 20 amino acids in length and is selected from the group consisting of (a) NH₂-KRIVQRIKDFLRNLVP-COOH (SEQ ID NO:13); (b) NH₂-KRIVQRIKDFLRNLVPR-COOH (SEQ ID NO:14); (c) NH₂-KRIVQRIKDFLRNLVPRT-COOH (SEQ ID NO:15); (d) NH₂-KRIVQRIKDFLRNLVP RTE-COOH (SEQ ID NO:16); and (e) NH₂-KRIVQRIKDFLRNLVPRTES-COOH (SEQ ID NO:17). In yet a further aspect the peptide is about 26 to 30 amino acids in length and is selected from the group consisting of (a) NH₂-KSKEKIGKEFKRIVQRIKDFLRNLVP-COOH (SEQ ID NO:18); (b) NH₂-KSKEKIGKEFKRIVQRIKDFLRNLVPR-COOH (SEQ ID NO:19); (c) NH₂-KSKEKIGKEFKRIVQRIKDFLRNLVPRT-COOH (SEQ ID NO:20); (d) NH₂-KSKEKIGKEFKRIVQRIKDFLRNLVP RTE-COOH (SEQ ID NO:21); and (e) NH₂-KSKEKIGKEFKRIVQRIKDFLRNLVPRTES-COOH (SEQ ID NO:22). In another embodiment the peptide is about 27 to 31 amino acids in length and is selected from the group consisting of (a) NH₂-RKSKEKIGKEFKRIVQRIKDFLRNLVP-COOH (SEQ ID NO:23); (b) NH₂-RKSKEKIGKEFKRIVQRIKDFLRNLVPR-COOH (SEQ ID NO:24); (c) NH₂-RKSKEKIGKEFKRIVQRIKDFLRNLVPRT-COOH (SEQ ID NO:25); (d) NH₂-RKSKEKIGKEFKRIVQRIKDFLRNLVP RTE-COOH (SEQ ID NO:26); (e) NH₂-

RKSKEKIGKEFKRIVQRIKDFLRNLPRTES-COOH (SEQ ID NO:27). In a specific embodiment, the peptide is 36 amino acids in length and consists of the sequence NH₂-

LGDDFRKSKEKIGKEFKRIVQRIKDFLRNLPRTES-COOH (SEQ ID NO:28).

[0007] The invention also provides a method of treating atopic dermatitis comprising contacting a subject having or suspected of having atopic dermatitis with an inhibiting effective amount of a cathelicidin functional fragment.

[0008] The details of one or more embodiments of the invention are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

DESCRIPTION OF DRAWINGS

[0009] FIG. 1 shows a pile up of protein sequence from canine cathelicidin (SEQ ID NO:9), PR-39 (SEQ ID NO:10); LL-37 (SEQ ID NO:6), murine CRAMP (SEQ ID NO:8) and goat cathelicidin (SEQ ID NO:11).

[0010] FIG. 2 shows that carbonate containing compounds increase the antimicrobial activity of LL-37. Carbonate was identified as the antimicrobial enhancing factor in mammalian tissue culture media via serial deletion of Minimal Essential Media (MEM) components. *Staphylococcus aureus* was cultured in 20% Tryptic Soy Broth (TSB), 10% Fetal Bovine Serum (FBS) and 70% of various media or media components with, or without, 32µM LL-37 to assess which components could increase antimicrobial activity. MEM buffers are 2200 mg/L NaHCO₃, 140 mg/L NaH₂PO₄ and 6800 mg/L NaCl. MEM salts are 200mg/L CaCl₂, 400 mg/L KCl, 98 mg/L MgSO₄. All solutions were adjusted to pH 7.4. Bacterial growth was measured as the change in turbidity at OD₆₀₀ and percent inhibition was determined by comparing bacterial growth in the presence of peptide to that in the absence of peptide. 32µM LL-37 inhibited *Staphalococcus aureus* growth poorly in TSB media alone, or with NaCl and FBS. In the presence of MEM buffers, inhibition was greatly increase and NaHCO₃, was determined to be the buffering

component responsible for this increase. This was confirmed with other carbonate containing compounds, 50mM KHCO₃ and Na₂CO₃, which also increased antimicrobial activity.

[0011] FIG. 3 shows that bicarbonate itself, not pH, is responsible for antimicrobial enhancement. Inhibition of *S. aureus* was measured in 20% TSB, 10% FBS 1mM NaH₂PO₄, 150mM NaCl, with either 50mM NaHCO₃ or 50mM Glycine buffer at various pH. Only bicarbonate containing media was able to confer increased antimicrobial activity to LL-37.

[0012] FIG. 4 shows that bicarbonate enhances activity of cathelicidin antimicrobial peptides. Inhibition of *Staph aureus* growth in the presence of various concentrations of human (LL-37), murine (CRAMP) and porcine (PR-39). Cathelicidin antimicrobial peptides was measured in 20% TSB, 1mM NaH₂PO₄, with, or without, 50mM NaHCO₃ at pH 7.4. The presence of NaHCO₃ greatly reduced the minimal inhibitory concentration (MIC) of all three peptides.

[0013] FIG. 5 demonstrates that 25mM NaHCO₃ enhances LL-37 activity without effecting bacterial growth. The growth of *S. aureus* in the presence, or absence, of 32 µM LL-37 was measured in 20% TSB, 10% FBS, 1mM NaH₂PO₄, 150mM NaCl, and various concentrations of NaHCO₃, all at pH 7.4. 25mM NaHCO₃ yielded complete inhibition of bacterial growth in the presence of LL-37, but not without peptide. High concentrations of NaHCO₃ retarded the growth of *S. aureus*.

[0014] FIG. 6 shows that NaHCO₃ enhances antimicrobial activity against gram negative and positive bacteria. *S. aureus* and *E. coli* were resistant to 16µM CRAMP without 50mM NaHCO₃, but became susceptible in its presence in 20% TSB, 1mM NaH₂PO₄ at pH 7.4. Group B Strep (GBS) and Salmonella were susceptible even without NaHCO₃.

[0015] FIG. 7 demonstrates that NaHCO₃ enables direct membrane disruption of *S. aureus*. Release of cytoplasmic expressed beta-galactosidase was measure from bacteria with and without the addition of NaHCO₃. (A) Polymyxin B induces greater leakage of cytoplasmic protein with carbonate. (B) LL-

37 induces greater leakage of cytoplasmic protein with carbonate.

[0016] FIG. 8 shows that NaHCO_3 enhances the activity of various antimicrobial peptides (see also FIG. 4). The ability of 50mM NaHCO_3 (EF) to enhance the activity of diverse antimicrobial peptides against *S. aureus* was tested in 20% TSB, 10% FBS, 1mM NaH_2PO_4 , 150mM NaCl, pH 7.4. The activity of all 3 Cathelicidins, Cryptdin-4 and Human Beta Defensin-2 (HBD-2) were enhanced by the addition of bicarbonate. Several other antimicrobial peptides were not enhanced.

[0017] FIG. 9 is an electron microscopy micrograph showing bacterial cell wall lysis by LL-37 and bicarbonate. *S. aureus* was grown for four hours in 20% TSB, 1mM NaH_2PO_4 with or without 25mM NaHCO_3 or 32uM LL-37. Bacteria were fixed in Karnovsky's Solution 24 hours and processed for EM on a Zeiss EM 10B Transmission Electron Microscope. The presence of 25mm NaHCO_3 alone had no visible effect on the bacterial cell wall. 32 μM LL-37 caused a small amount of damage to bacterial cell walls in the absence of NaHCO_3 , but totally ablated them in its presence, causing cell lysis. Mag 42,000X, insets are 110,000X.

[0018] FIG. 10A-B shows soluble antimicrobial activity on human skin. Human sweat was concentrated 50X and separated by HPLC on C18. a) Absorbance profile at 214 nm for eluted material from 35% to 60% acetonitrile, inset: complete absorbance profile of eluted materials. b) Ability of material eluted in Fig 1a to inhibit growth of *S. aureus* mprF is shown as diameter of zone of *S. aureus* mprF inhibition. Several antimicrobial fractions were detected. Mass spectrometry identified previously described antimicrobials; fractions labeled (1) and (3) are dermcidin and DCD-1L respectively (MW 4701, MW 4818, respectively) confirmed by N-terminal sequencing ((1): SSLLEKGLDGA, (3): SSLLE, (2): LL-37 identified by mass spectrometry (MW 4493) and immunoblot. Data representative of single experiment repeated 5 times with separate sweat preparations.

[0019] FIG. 11A-B shows serine protease in sweat enhances cathelicidin antimicrobial activity. Antibacterial activity evaluated by radial diffusion assay against *S. aureus* mprF after incubation of LL-37 (32uM) in sweat. a) Increase in the inhibition zone is seen when incubated in sweat but not 10 mM PBS or distilled water (DW). b) Diameters of inhibition zone after 6hr incubation at 37°C in (SWT buffer; sweat buffer salts alone), (PBS), (D.W.; distilled water), (SWT; sterile filtered human sweat at 37°C), (SWT at 4°C), (SWT with PI, with protease inhibitor cocktail). c) Action of specific protease inhibitors on gain of antimicrobial activity. Data show increase in inhibition zone at 37°C after 6hr compared to 0hr. Serine protease inhibitors AEBSF and Aprotinin were most effective. N.E.I. = neutrophil elastase inhibitor, L.E.I. = leukocyte elastase inhibitor. Data are triplicate determinations \pm SEM from single experiment representative of 3.

[0020] FIG. 12A-B shows purification of novel cathelicidin peptides generated from LL-37 a) Human sweat was separated by HPLC on C18. Absorbance profile at 214 nm is shown for eluted material from 30% to 60% acetonitrile. Crude is sweat prior to addition of LL-37, overlay plots show separate runs of sweat following addition of 32nmol of LL-37 and incubation for 0 to 24 hr at 37°C. b) Antibacterial activity with radial diffusion assay against *S. aureus* mprF of fractions eluted from 24hr sample in a. Peaks with antimicrobial activity are labeled 1 and 2 and 3.

[0021] FIG. 13A-D shows the identification of novel cathelicidin peptides generated from LL-37. Following purification shown in Figure 3, major bioactive fractions were identified. a) peak (1) in Fig 12a identified as KR-20 by mass spec. (MW 2468), and N-terminal sequence KRIVQRIKDVF (SEQ ID NO:2), b) peak (2) detected 2 peptides; RK-31 and KS-30 (MW 3647, 3803, and RKSKEKIG (SEQ ID NO:3), KSKEKIGK (SEQ ID NO:4), respectively), c) Western blot analysis with anti-LL-37 was done on all fractions from Fig 3, shown are fractions eluting at acetonitrile concentrations 46-55. Peaks labeled

(2) and (3) in Figure 3 were immunoreactive. d) peak (3) identified as LL-37 (MW 4493). Data from single experiment representative of 3.

[0022] FIG. 14 shows the processing of LL-37 enhances antimicrobial activity. The antimicrobial activity of cathelicidin peptides was evaluated by radial diffusion assay against (a) *S.aureus* , (b) *E.coli* , (c) solution assay against *C.albicans* and (d) Group A Streptococci . The antimicrobial activity of each peptide was evaluated in 10%TSB/10mM phosphate buffer with several NaCl concentraions against *E.coli* (e) and *S.aureus* (f). Data shown are representative of triplicate determinations.

[0023] FIG. 15 shows that processing of LL-37 decreases ability to stimulate keratinocyte IL-8. Cathelicidin peptides were added to culture of normal human keratinocytes at a final concentration of 3 or 10 mM then IL-8 release determined after 8 hr. All samples were endotoxin free by limulus assay. Data are mean \pm SEM of triplicate determinations.

[0024] FIG. 16 is a graph showing that LL-37 induces neutrophil and mast cell chemotaxis.

[0025] FIG. 17 is a graph showing that CRAMP has similar effect in mouse dendritic cells.

[0026] FIG. 18A-C show that CRAMP inhibits antigen presentation *in vitro*.

[0027] FIG. 19A-C shows the identification of cathelicidin function fragments on the normal skin surface by HPLC.

[0028] FIG. 20 shows a schematic of cathelicidin processing on the normal skin surface.

DETAILED DESCRIPTION

[0029] So long as there is an apparent need for protection against infection the evaluation of host responses that contribute to control of bacterial and viral infections in general is an important goal. The disclosure provides peptides useful in treating bacterial, viral and other microbial infections.

[0030] In humans, there are several classes of known antimicrobial peptides (AMPs) including α -defensins, β -

defensins, and cathelicidins. Cathelicidins are found in several mammalian species. Production of cathelicidins is induced in response to epithelial wounding or infectious challenge, or suppressed by the virulence mechanisms of certain bacterial pathogens, e.g., *Shigella dysenteriae*. Cathelicidin expression is also differentially effected in certain chronic inflammatory disorders. In psoriasis, cathelicidin levels are elevated and secondary infection is rare, whereas in atopic dermatitis cathelicidin expression is deficient and bacterial or viral superinfection is common. Therapeutic benefits of cathelicidin have been demonstrated experimentally, including decreased bacterial colonization of skin wounds following topical administration and improved pulmonary bacterial clearance with cathelicidin overexpression through viral gene transfer.

[0031] Cathelicidin proteins are composed of two distinct domains: an N-terminal "cathelin-like" or "prosequence" domain and the C-terminal domain of the mature AMP. The C-terminal domains of cathelicidins were among the earliest mammalian AMPs to show potent, rapid, and broad-spectrum killing activity. The term "cathelin-like" derives from the similarity of the N-terminal sequence with that of cathelin, a 12 kDa protein isolated from porcine neutrophils that shares similarity with the cystatin superfamily of cysteine protease inhibitors.

[0032] Cathelicidins are expressed in neutrophils and myeloid bone marrow cells and most epithelial sources, and were the first AMPs discovered in mammalian skin due to their presence in wound fluid. In the neutrophil, cathelicidins are synthesized as full-length precursor and targeted to the secondary granules where they are stored. Upon stimulation, the full-length cathelicidin protein is proteolytically processed to unleash the microbicidal activity of the C-terminal peptide from the cathelin-like domain.

[0033] The C-terminal 37 amino acids of human cathelicidin (LL-37) has been characterized. LL-37 was originally referred to as FALL39, named for the first 4 N-terminal amino acids of

this domain and the total number of residues (*i.e.*, 39). LL-37 is a peptide predicted to contain an amphipathic alpha helix and lacks cysteine, making it different from all other previously isolated human peptide antibiotics of the defensin family, each of which contain 3 disulfide bridges. Full length human cathelicidin (sometimes referred to as full length LL-37) comprises the cathelin-like precursor protein and the C-terminal LL-37 peptide, thus comprising 170 amino acids (SEQ ID NO:6).

[0034] The polypeptide comprising SEQ ID NO:6 has a number of distinct domains. For example, a signal domain comprising a sequence as set forth from about 1 to about 29-31 of SEQ ID NO:6 is present. The signal domain is typically cleaved following amino acid number 30 of SEQ ID NO:6, however, one of skill in the art will recognize that depending upon the enzyme used, the expression system used and/or the conditions under which proteolytic cleavage of the polypeptide takes place, the cleavage site may vary from 1 to 3 amino acid in either direction of amino acid number 30 of SEQ ID NO:6. Another domain comprises the N-terminal domain, referred to as the cathelin-like domain. The cathelin-like domain comprises from about amino acid 29 (*e.g.*, 29-31) to about amino acid 128 (*e.g.*, 128-131) of SEQ ID NO:6. Yet another domain of SEQ ID NO:6 comprises the C-terminal domain referred to as LL-37. The LL-37 domain comprises from about amino acid 128 (*e.g.*, 128-134) to amino acid 170 of SEQ ID NO:6.

[0035] LL-37 comprises the amino acid sequence set forth in SEQ ID NO:6. The human cDNA sequence for LL-37 is set forth in SEQ ID NO:5. The coding sequence of an active fragment of LL-37 can be identified with reference to the cDNA sequence provided in SEQ ID NO:5 without difficulty. Accordingly the corresponding coding sequences of the fragments identified herein are also provided by the disclosure.

[0036] The disclosure demonstrates human and murine C-terminal domains of cathelicidins, and functional fragments thereof, have antimicrobial and antiviral activity *in vitro* and *in vivo*.

[0037] The invention demonstrates that a minimal peptide domain of the C-terminal of cathelicidins comprising specific structural elements have antibacterial, antiviral and/or antimicrobial effects. The mechanisms by which cationic human antimicrobial peptides kill bacteria and fungi are generally through binding of the peptide to the microbial cell membrane, after which the membrane's proton gradient and integrity are lost.

[0038] The invention provides a peptide consensus sequence found in a number of peptides which inhibit bacterial growth and/or viral growth and mimic the activity of LL-37, CRAMP, and/or FALL-39. This consensus sequence is 18 amino acids in length and is found in LL-37, CRAMP and FALL-39. The consensus sequences corresponds to amino acids 151-166 of full-length LL-37 (SEQ ID NO:6), and amino acids 154-169 of CRAMP (SEQ ID NO:8). The peptides of the invention consist of 16-36 amino acids and contain $\text{NH}_2\text{-X}_1\text{X}_2\text{X}_3\text{X}_4\text{X}_5\text{X}_6\text{IKX}_7\text{FX}_8\text{X}_9\text{X}_{10}\text{LX}_{11}\text{X}_{12}\text{-COOH}$ (SEQ ID NO:1), wherein X_1 , X_2 , and X_6 are individually K or R; wherein X_3 is I or K; wherein X_4 is V or G; wherein X_5 is Q or R; wherein X_7 is any amino acid; wherein X_8 is L or F; wherein X_9 is R or Q; X_{10} is N or K; X_{11} is V or A; and wherein X_{12} is P or L. A pile up of related cathelicidin proteins is provided in FIG. 1.

[0039] In one aspect, the invention provides active fragments of LL-37 and CRAMP that inhibit bacterial growth and viral infection. For example, active fragments of LL-37 include SEQ ID NO:6 from about amino acid XX_1 to XX_2 , wherein XX_1 is an amino acid between and including 135 and 151 (*i.e.*, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, and 151) and wherein XX_2 is an amino acid between and including 166 and 170 (*i.e.*, 166, 167, 168, 169, and 170). Table 1 sets forth exemplary sequence of cathelicidin functional fragments.

[0040] Table 1

Sequence	SEQ ID NO:6 from aa to aa
RKSKEKIGKEFKRIVQRIKDFLRNLPRTES	141 to 170 (SEQ ID NO:27)
KSKEKIGKEFKRIVQRIKDFLRNLPRTES	142 to 170 (SEQ ID NO:22)

KRIVQRIKDFLRNLVPRTES	151 to 170 (SEQ ID NO:17)
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[0041] The pile up alignments of FIG. 1 are useful in identifying amino acids that may be substituted (i.e., that are not highly conserved) in peptide fragments of the invention. For example, with reference to FIG.1 it will be apparent that bolded amino acids are conserved compared to the amino acids presented in regular text. Accordingly, substitutions of amino acid at places in the peptide in regular text will likely be tolerated in contrast to non-conservative substitutions of bolded amino acids.

[0042] The term "antimicrobial" as used herein means that the peptide destroys, or inhibits or prevents the growth or proliferation of, a microbe (e.g., a bacterium, fungus, and/or virus). Likewise, the term "antiviral" as used herein means that a peptide destroys, or inhibits or prevents the growth or proliferation of a virus or a virus-infected cell. The term "anti-tumor" as used herein means that a peptide prevents, inhibits the growth of, or destroys, a tumor cell(s). Similarly, the term "antifungal" means that a peptide prevents, destroys, or inhibits the growth of a fungus.

[0043] As used herein, the term "cathelicidin functional fragment" refers to a chain of amino acids that is about 16 to 36 amino acids in length and (i) contains a sequence as set forth in SEQ ID NO:1, (ii) is a fragment of the C-terminus of SEQ ID NO:6 containing SEQ ID NO:1, (iii) is an active fragment of LL-37 from about amino acid XX₁ to XX₂ of SEQ ID NO:6, wherein XX₁ is an amino acid between and including 135 and 151 (i.e., 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, and 151) and wherein XX₂ is an amino acid between and including 166 and 170 (i.e., 166, 167, 168, 169, and 170), or (iv) a fragment set forth in Table 1. A peptide is "cationic" if it has a pKa greater than 9.0. Typically, at least four of the amino acid residues of the cationic peptide are positively charged residues, e.g., lysine and arginine. "Positively charged" refers to the side chain

of an amino acid residue that has a net positive charge at pH 7.0.

[0044] The term "purified" and "substantially purified" as used herein refers to a polypeptide or peptide that is substantially free of other proteins, lipids, and polynucleotides (e.g., cellular components with which an *in vivo*-produced polypeptide or peptide would naturally be associated). Typically, the peptide is at least 70%, 80%, or most commonly 90% pure by weight.

[0045] The disclosure also includes analogs, derivatives, conservative variations, and cathelicidin functional fragment variants of the enumerated cathelicidin functional fragments, provided that the analog, derivative, conservative variation, or variant has a detectable antimicrobial antibacterial and/or antiviral activity. It is not necessary that the analog, derivative, variation, or variant have activity identical to the activity of the peptide from which the analog, derivative, conservative variation, or variant is derived. For example, using the alignment provided in Figure 1, one of skill in the art can readily identify conserved amino acids and non-conserved amino acid. Using the alignment, one of skill in the art can readily identify which amino acid may be modified or substituted.

[0046] A cathelicidin functional fragment "variant" is an antimicrobial, antibacterial and/or antiviral peptide that is an altered form of a referenced cathelicidin functional fragment. For example, the term "variant" includes a cathelicidin functional fragment produced by the method disclosed herein in which at least one amino acid (e.g., from about 1 to 10 amino acids) of a reference peptide is substituted with another amino acid. The term "reference" peptide means any of the cathelicidin functional fragments of the disclosure (e.g., as defined in the above formula (SEQ ID NO:1) as well as the specific fragments described in Table 1 from which a variant, derivative, analog, or conservative variation is derived. Included within the term "derivative" is a hybrid peptide that includes at least a portion of each

of two cathelicidin functional fragments (e.g., 30-80% of each of two cathelicidin functional fragments). Derivatives can be produced by adding one or a few (e.g., 1-5) amino acids to a peptide of the disclosure without completely inhibiting the activity of the peptide. In addition, C-terminal derivatives, e.g., C-terminal methyl esters, can be produced and are encompassed by the disclosure.

[0047] The disclosure also includes peptides that are conservative variations of those peptides as exemplified herein. The term "conservative variation" as used herein denotes a peptide or polypeptide in which at least one amino acid is replaced by another, biologically similar residue. Examples of conservative variations include the substitution of one hydrophobic residue, such as isoleucine, valine, leucine, alanine, cysteine, glycine, phenylalanine, proline, tryptophan, tyrosine, norleucine or methionine for another, or the substitution of one polar residue for another, such as the substitution of arginine for lysine, glutamic for aspartic acid, or glutamine for asparagine, and the like. Neutral hydrophilic amino acids that can be substituted for one another include asparagine, glutamine, serine and threonine. The term "conservative variation" also encompasses a peptide having a substituted amino acid in place of an unsubstituted parent amino acid; typically, antibodies raised to the substituted peptide or polypeptide also specifically bind the unsubstituted peptide or polypeptide.

[0048] Cathelicidin functional fragment variants of the disclosure can be identified by screening a large collection, or library, of random peptides or polypeptides using, for example, one of a number of animal models such as CRAMP knockout mice that display increased susceptibility to skin infections. Cathelicidin functional fragment variants can be, for example, a population of peptides related in amino acid sequence to SEQ ID NO:1 by having various substitutions based upon, for example, the sequences as set forth in the pile up of Fig. 1, and the sequence set forth in Table 1.

[0049] Peptide libraries include, for example, tagged chemical libraries comprising peptides and peptidomimetic molecules. Peptide libraries also comprise those generated by phage display technology. Phage display technology includes the expression of peptide molecules on the surface of phage as well as other methodologies by which a protein ligand is or can be associated with the nucleic acid, which encodes it. Methods for the production of phage display libraries, including vectors and methods of diversifying the population of peptides, which are expressed, are known in the art (see, for example, Smith and Scott, *Methods Enzymol.* 217:228-257 (1993); Scott and Smith, *Science* 249:386-390 (1990); and Huse, WO 91/07141 and WO 91/07149). These or other known methods can be used to produce a phage display library, from which the displayed peptides can be cleaved and assayed for antibacterial activity. If desired, a population of peptides can be assayed for activity, and an active population can be subdivided and the assay repeated in order to isolate an active peptide from the population. Other methods for producing peptides useful in the disclosure include, for example, rational design and mutagenesis based on the amino acid sequences of a cathelicidin functional fragment as set forth in SEQ ID NO:1 and 6 and Table 1, for example.

[0050] A cathelicidin functional fragment variant can be a peptide mimetic, which is a non-amino acid chemical structure that mimics the structure of, for example, a cathelicidin functional fragment of SEQ ID NO:1 and the related peptides of Table 1, yet retains antimicrobial/antibacterial/antiviral. Such a mimetic generally is characterized as exhibiting similar physical characteristics such as size, charge or hydrophobicity in the same spatial arrangement found in the cathelicidin functional fragment counterpart. A specific example of a peptide mimetic is a compound in which the amide bond between one or more of the amino acids is replaced, for example, by a carbon-carbon bond or other bond well known in the art (see, for example, Sawyer, *Peptide Based Drug Design*, ACS, Washington (1995)).

[0051] The amino acids of a cathelicidin functional fragment, cathelicidin functional fragment variant or peptidomimetic of the disclosure are selected from the twenty naturally occurring amino acids, including, unless stated otherwise, L-amino acids and D-amino acids. The use of D-amino acids are particularly useful for increasing the life of a peptide or polypeptide. Polypeptides or peptides incorporating D-amino acids are resistant to proteolytic digestion. The term amino acid also refers to compounds such as chemically modified amino acids including amino acid analogs, naturally occurring amino acids that are not usually incorporated into proteins such as norleucine, and chemically synthesized compounds having properties known in the art to be characteristic of an amino acid, provided that the compound can be substituted within a peptide such that it retains its biological activity. For example, glutamine can be an amino acid analog of asparagine, provided that it can be substituted within an active fragment of a cathelicidin functional fragment, variant and the like such that it retains its antimicrobial/antibacterial/antiviral activity. Other examples of amino acids and amino acids analogs are listed in Gross and Meienhofer, *The Peptides: Analysis, Synthesis, Biology*, Academic Press, Inc., New York (1983). An amino acid also can be an amino acid mimetic, which is a structure that exhibits substantially the same spatial arrangement of functional groups as an amino acid but does not necessarily have both the "-amino" and "-carboxyl" groups characteristic of an amino acid.

[0052] Peptides of the disclosure can be synthesized by commonly used methods such as those that include t-BOC or Fmoc protection of alpha-amino groups. Both methods involve stepwise synthesis in which a single amino acid is added at each step starting from the C terminus of the peptide (See, Coligan, et al., *Current Protocols in Immunology*, Wiley Interscience, 1991, Unit 9). Peptides of the disclosure can also be synthesized by the well known solid phase peptide synthesis methods such as those described by Merrifield, J.

Am. Chem. Soc., 85:2149, 1962; and Stewart and Young, Solid Phase Peptides Synthesis, Freeman, San Francisco, 1969, pp.27-62, using a copoly(styrene-divinylbenzene) containing 0.1-1.0 mMol amines/g polymer. On completion of chemical synthesis, the peptides can be deprotected and cleaved from the polymer by treatment with liquid HF-10% anisole for about 1/4-1 hours at 0°C. After evaporation of the reagents, the peptides are extracted from the polymer with a 1% acetic acid solution, which is then lyophilized to yield the crude material. The peptides can be purified by such techniques as gel filtration on Sephadex G-15 using 5% acetic acid as a solvent.

Lyophilization of appropriate fractions of the column eluate yield homogeneous peptide, which can then be characterized by standard techniques such as amino acid analysis, thin layer chromatography, high performance liquid chromatography, ultraviolet absorption spectroscopy, molar rotation, or measuring solubility. If desired, the peptides can be quantitated by the solid phase Edman degradation.

[0053] The activity of the peptides of the disclosure can be determined using conventional methods known to those of skill in the art, such as in a "minimal inhibitory concentration (MIC)", whereby the lowest concentration at which no change in OD is observed for a given period of time is recorded as the MIC. Alternatively, a "fractional inhibitory concentration (FIC)" assay can be used to measure synergy between the peptides of the disclosure, or the peptides in combination with known antibiotics. FICs can be performed by checkerboard titrations of peptides in one dimension of a microtiter plate, and of antibiotics in the other dimension, for example. The FIC is a function of the impact of one antibiotic on the MIC of the other and vice versa. A FIC of 1 indicates that the influence of the compounds is additive and a FIC of less than 1 indicates that the compounds act synergistically.

[0054] Peptides of the disclosure can be synthesized by commonly used methods such as those that include t-BOC or FMOC protection of alpha-amino groups. Both methods involve

stepwise synthesis in which a single amino acid is added at each step starting from the C-terminus of the peptide (See, Coligan, et al., Current Protocols in Immunology, Wiley Interscience, 1991, Unit 9). Peptides of the disclosure can also be synthesized by the well known solid phase peptide synthesis methods such as those described by Merrifield, J. Am. Chem. Soc., 85:2149, 1962; and Stewart and Young, Solid Phase Peptides Synthesis, Freeman, San Francisco, 1969, pp.27-62) using a copoly(styrene-divinylbenzene) containing 0.1-1.0 mMol amines/g polymer. On completion of chemical synthesis, the peptides can be deprotected and cleaved from the polymer by treatment with liquid HF-10% anisole for about 1/4-1 hours at 0°C. After evaporation of the reagents, the peptides are extracted from the polymer with a 1% acetic acid solution, which is then lyophilized to yield the crude material. The peptides can be purified by such techniques as gel filtration on Sephadex G-15 using 5% acetic acid as a solvent. Lyophilization of appropriate fractions of the column eluate yield homogeneous peptide, which can then be characterized by standard techniques such as amino acid analysis, thin layer chromatography, high performance liquid chromatography, ultraviolet absorption spectroscopy, molar rotation, or measuring solubility. If desired, the peptides can be quantitated by the solid phase Edman degradation.

[0055] The disclosure also includes isolated polynucleotides (e.g., DNA, cDNA, or RNA) encoding the peptides of the disclosure. Included are polynucleotides that encode analogs, mutants, conservative variations, and variants of the peptides described herein. The term "isolated" as used herein refers to a polynucleotide that is substantially free of proteins, lipids, and other polynucleotides with which an *in vivo*-produced polynucleotide naturally associates. Typically, the polynucleotide is at least 70%, 80%, or 90% isolated from other matter, and conventional methods for synthesizing polynucleotides *in vitro* can be used in lieu of *in vivo* methods. As used herein, "polynucleotide" refers to a polymer of deoxyribonucleotides or ribonucleotides, in the

form of a separate fragment or as a component of a larger genetic construct (e.g., by operably linking a promoter to a polynucleotide encoding a peptide of the disclosure). Numerous genetic constructs (e.g., plasmids and other expression vectors) are known in the art and can be used to produce the peptides of the disclosure in cell-free systems or prokaryotic or eukaryotic (e.g., yeast, insect, or mammalian) cells. By taking into account the degeneracy of the genetic code, one of ordinary skill in the art can readily synthesize polynucleotides encoding the peptides of the disclosure. The polynucleotides of the disclosure can readily be used in conventional molecular biology methods to produce the peptides of the disclosure.

[0056] In one embodiment, a cathelicidin functional fragment polynucleotide/nucleic acid of the disclosure comprises a sequence of SEQ ID NO:5. In one aspect, a polynucleotide encoding a cathelicidin function fragment comprises SEQ ID NO:5 from about nucleotide 451 to 498, from about nucleotide 451 to 501, from about nucleotide 451 to 504, from about nucleotide 451 to 507, from about nucleotide 451 to 510, from about nucleotide 421 to 498, from about nucleotide 421 to 501, from about nucleotide 421 to 504, from about nucleotide 421 to 507, from about nucleotide 421 to 510, from about nucleotide 418 to 498, from about nucleotide 418 to 501, from about nucleotide 418 to 504, from about nucleotide 418 to 507, from about nucleotide 418 to 510, from about nucleotide 403 to 498, from about nucleotide 403 to 501, from about nucleotide 403 to 504, from about nucleotide 403 to 507, and from about nucleotide 403 to 510.

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1   taaagcaaac cccagccac accctggcag gcagccaggg atgggtggat caggaaggct
61  cctgggtggg cttttgcatc aggctcaggc tgggcataaa ggaggctcct gtgggctaga
121 gggaggcaga catggggacc atgaagaccc aaagggatgg ccactccctg gggcggtggt
181 cactggtgct cctgctgctg ggctgtgga tgctctggtc catcattgcc caggctctca
241 gctacaagga agctgtgctt cgtgctatag atggcatcaa ccagcgggtcc tcggatgcta
301 acctctaccg cctcctggac ctggacccca ggcccacgat ggatggggac ccagacacgc
361 caaagcctgt gagcttcaca gtgaaggaga cagtgtgccc caggacgaca cagcagtcac
421 cagaggattg tgacttcaag aaggacgggc tgggtgaagcg gtgtatgggg acagtgacct
481 tcaaccaggc caggggctcc ttgacatca gttgtgataa ggataacaag agatttgccc
541 tgctgggtga tttcttccgg aaatctaaag agaagattgg caaagagttt aaaagaattg
601 tccagagaat caaggatttt ttgcggaatc ttgtaccacg gacagagtcc tagtgtgtgc
661 cctaccctgg ctcaggcttc tgggtctctga gaaataaact atgagagcaa tttcaaaaaa
721 aaaaaaaaaa aaaaaaaaaa (SEQ ID NO:5)

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In another example, a polynucleotide encoding a cathelicidin functional fragment of the disclosure comprises a sequence of SEQ ID NO:7. In one aspect, a polynucleotide encoding a cathelicidin functional fragment comprises SEQ ID NO:7 from about nucleotide 460 to nucleotide 507.

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1   atgcagttcc agagggacgt cccctccctg tggtctgtggc ggtcactatc actgctgctg
61  ctactggggc tggggttctc ccagaccccc agctacaggg atgctgtgct ccgagctgtg
121 gatgacttca accagcagtc cctagacacc aatctctacc gtctcctgga cctggatcct
181 gagccccaag gggacgagga tccagatact cccaagtctg tgaggttccg agtgaaggag
241 actgtatgtg gcaaggcaga gcggcagcta cctgagcaat gtgccttcaa ggaacagggg
301 gtggtgaagc agtgtatggg ggcagtcacc ctgaaccggg ccgctgattc ttttgacatc
361 agctgtaacg agcctggtgc acagcccttt cggttcaaga aaatttcccg gctggctgga
421 cttctccgca aaggtgggga gaagattggt gaaaagctta agaaaattgg ccagaaaatt
481 aagaattttt ttcagaaact tgtccctcag ccagagtag (SEQ ID NO:7)

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[0057] Such polynucleotides include naturally occurring, synthetic, and intentionally manipulated polynucleotides. For example, a cathelicidin functional fragment peptide or polynucleotide may be subjected to site-directed mutagenesis. A cathelicidin functional fragment polynucleotide includes sequences that are degenerate as a result of the genetic code. There are 20 natural amino acids, most of which are specified by more than one codon. Therefore, all degenerate nucleotide sequences are included so long as the amino acid sequence of a cathelicidin functional fragment peptide or variant encoded by the polynucleotide is functionally unchanged. Accordingly, a polynucleotide of the invention includes (i) a polynucleotide encoding a cathelicidin functional fragment; (ii) a polynucleotide encoding SEQ ID NO:1 or a variant thereof, or SEQ ID NO:2-4 or a variant thereof; (iii) a polynucleotide comprising SEQ ID NO:5 from about nucleotide 451 to 498, from about nucleotide 451 to 501, from about nucleotide 451 to 504, from about nucleotide 451 to 507, from about nucleotide 451 to 510, from about nucleotide 421 to 498, from about nucleotide 421 to 501, from about nucleotide 421 to 504, from about nucleotide 421 to 507, from about nucleotide 421 to 510, from about nucleotide 418 to 498, from about nucleotide 418 to 501, from about nucleotide 418 to 504, from about nucleotide 418 to 507, from about nucleotide 418 to 510, from about nucleotide

403 to 498, from about nucleotide 403 to 501, from about nucleotide 403 to 504, from about nucleotide 403 to 507, and/or from about nucleotide 403 to 510; (iv) a polynucleotide of (iii), wherein T is U; and (v) a polynucleotide comprising a sequence that is complementary to (iii) and (iv) above. It will be recognized that a cathelicidin functional fragment polynucleotide, may be operably linked to a second heterologous polynucleotide such as a promoter or a heterologous sequence encoding a desired peptide or polypeptide sequence.

[0058] The term "isolated" as used herein refers to a nucleic acid that is substantially free of proteins, lipids, and other nucleic acids with which an *in vivo*-produced nucleic acids naturally associated. Typically, the nucleic acid is at least 70%, 80%, 90% or more pure by weight, and conventional methods for synthesizing nucleic acids *in vitro* can be used in lieu of *in vivo* methods. As used herein, "nucleic acid" or "polynucleotide" refers to a polymer of deoxyribonucleotides or ribonucleotides, in the form of a separate fragment or as a component of a larger genetic construct (e.g., by operably linking a promoter to a nucleic acid encoding a peptide of the disclosure). Numerous genetic constructs (e.g., plasmids and other expression vectors) are known in the art and can be used to produce the peptides of the disclosure in cell-free systems or prokaryotic or eukaryotic (e.g., yeast, insect, or mammalian) cells. By taking into account the degeneracy of the genetic code, one of ordinary skill in the art can readily synthesize nucleic acids encoding the polypeptides of the disclosure. The nucleic acids of the disclosure can readily be used in conventional molecular biology methods to produce the peptides of the disclosure.

[0059] Polynucleotides encoding the cathelicidin functional fragments of the disclosure can be inserted into an "expression vector." The term "expression vector" refers to a genetic construct such as a plasmid, virus or other vehicle known in the art that can be engineered to contain a polynucleotide encoding a peptide or polypeptide of the

disclosure. Such expression vectors are typically plasmids that contain a promoter sequence that facilitates transcription of the inserted genetic sequence in a host cell. The expression vector typically contains an origin of replication, and a promoter, as well as genes that allow phenotypic selection of the transformed cells (e.g., an antibiotic resistance gene). Various promoters, including inducible and constitutive promoters, can be utilized in the disclosure. Typically, the expression vector contains a replicon site and control sequences that are derived from a species compatible with the host cell.

[0060] Transformation or transfection of a host cell with a polynucleotide of the disclosure can be carried out using conventional techniques well known to those skilled in the art. For example, where the host cell is *E. coli*, competent cells that are capable of DNA uptake can be prepared using the CaCl_2 , MgCl_2 or RbCl methods known in the art. Alternatively, physical means, such as electroporation or microinjection can be used. Electroporation allows transfer of a polynucleotide into a cell by high voltage electric impulse. Additionally, polynucleotides can be introduced into host cells by protoplast fusion, using methods well known in the art. Suitable methods for transforming eukaryotic cells, such as electroporation and lipofection, also are known.

[0061] "Host cells" encompassed by of the disclosure are any cells in which the polynucleotides of the disclosure can be used to express the cathelicidin functional fragments of the disclosure. The term also includes any progeny of a host cell. Host cells, which are useful, include bacterial cells, fungal cells (e.g., yeast cells), plant cells and animal cells. For example, host cells can be a higher eukaryotic cell, such as a mammalian cell, or a lower eukaryotic cell, such as a yeast cell, or the host cell can be a prokaryotic cell, such as a bacterial cell. Introduction of the construct into the host cell can be effected by calcium phosphate transfection, DEAE-Dextran mediated transfection, or electroporation (Davis, L., Dibner, M., Battey, I., Basic

Methods in Molecular Biology (1986)). As representative examples of appropriate hosts, there may be mentioned: fungal cells, such as yeast; insect cells such as Drosophila S2 and Spodoptera Sf9; animal cells such as CHO, COS or Bowes melanoma; plant cells, and the like. The selection of an appropriate host is deemed to be within the scope of those skilled in the art from the teachings herein.

[0062] Host cells can be eukaryotic host cells (e.g., mammalian cells). In one aspect, the host cells are mammalian production cells adapted to grow in cell culture. Examples of such cells commonly used in the industry are CHO, VERO, BHK, HeLa, CV1 (including Cos; Cos-7), MDCK, 293, 3T3, C127, myeloma cell lines (especially murine), PC12 and W138 cells. Chinese hamster ovary (CHO) cells are widely used for the production of several complex recombinant proteins, e.g. cytokines, clotting factors, and antibodies (Brasel et al., Blood 88:2004-2012, 1996; Kaufman et al., J.Biol Chem 263: 6352-6362, 1988; McKinnon et al., J Mol Endocrinol 6:231-239, 1991; Wood et al., J. Immunol 145:3011-3016, 1990). The dihydrofolate reductase (DHFR)-deficient mutant cell lines (Urlaub et al., Proc Natl Acad Sci USA 77:4216-4220, 1980) are the CHO host cell lines commonly used because the efficient DHFR selectable and amplifiable gene expression system allows high level recombinant protein expression in these cells (Kaufman, Meth Enzymol 185:527-566, 1990). In addition, these cells are easy to manipulate as adherent or suspension cultures and exhibit relatively good genetic stability. CHO cells and recombinant proteins expressed in them have been extensively characterized and have been approved for use in clinical manufacturing by regulatory agencies.

[0063] Polynucleotides encoding the peptides of the disclosure can be isolated from a cell (e.g., a cultured cell), or they can be produced *in vitro*. A DNA sequence encoding a cathelicidin functional fragment of interest can be obtained by: 1) isolation of a double-stranded DNA sequence from genomic DNA; 2) chemical manufacture of a polynucleotide such that it encodes the cathelicidin functional fragment of

interest; or 3) *in vitro* synthesis of a double-stranded DNA sequence by reverse transcription of mRNA isolated from a donor cell (*i.e.*, to produce cDNA).

[0064] Included in the disclosure are polynucleotides that encode analogs, mutants, conservative variations, and variants of the peptides described herein. For example, an isolated polynucleotide encoding a cathelicidin functional fragment of the disclosure can comprise the sequence of SEQ ID NO:5 from about nucleotide 451 to 498, from about nucleotide 451 to 501, from about nucleotide 451 to 504, from about nucleotide 451 to 507, from about nucleotide 451 to 510, from about nucleotide 421 to 498, from about nucleotide 421 to 501, from about nucleotide 421 to 504, from about nucleotide 421 to 507, from about nucleotide 421 to 510, from about nucleotide 418 to 498, from about nucleotide 418 to 501, from about nucleotide 418 to 504, from about nucleotide 418 to 507, from about nucleotide 418 to 510, from about nucleotide 403 to 498, from about nucleotide 403 to 501, from about nucleotide 403 to 504, from about nucleotide 403 to 507, and from about nucleotide 403 to 510.

[0065] Such polynucleotides include naturally occurring, synthetic, and intentionally manipulated polynucleotides. For example, a cathelicidin functional fragment or variant polynucleotide may be subjected to site-directed mutagenesis. A cathelicidin functional fragment or variant polynucleotide includes sequences that are degenerate as a result of the genetic code. There are 20 natural amino acids, most of which are specified by more than one codon. Therefore, all degenerate nucleotide sequences are included so long as the amino acid sequence of a cathelicidin functional fragment or variant encoded by the nucleotide sequence is functionally unchanged. Accordingly, a polynucleotide of the disclosure includes (i) a polynucleotide encoding a cathelicidin functional fragment or variant; (ii) a polynucleotide encoding SEQ ID NO:1 or a variant thereof, or SEQ ID NO:2-4 or a variant thereof; (iii) a polynucleotide comprising SEQ ID NO:5 from about nucleotide 451 to 498, from about nucleotide 451 to

501, from about nucleotide 451 to 504, from about nucleotide 451 to 507, from about nucleotide 451 to 510, from about nucleotide 421 to 498, from about nucleotide 421 to 501, from about nucleotide 421 to 504, from about nucleotide 421 to 507, from about nucleotide 421 to 510, from about nucleotide 418 to 498, from about nucleotide 418 to 501, from about nucleotide 418 to 504, from about nucleotide 418 to 507, from about nucleotide 418 to 510, from about nucleotide 403 to 498, from about nucleotide 403 to 501, from about nucleotide 403 to 504, from about nucleotide 403 to 507, and from about nucleotide 403 to 510; (iv) a polynucleotide of (iii), wherein T is U; and (v) a polynucleotide comprising a sequence that is complementary to (iii) and (iv) above. A "polynucleotide" of the disclosure also includes those polynucleotides capable of hybridizing, under stringent hybridization conditions, to sequences of (iii)-(v), above. "Stringent hybridization conditions" refers to an overnight incubation at 42 °C in a solution comprising 50% formamide, 5xSSC (750 mM NaCl, 75 mM trisodium citrate), 50 mM sodium phosphate (pH 7.6), 5x Denhardt's solution, 10% dextran sulfate, and 20 µg/ml denatured, sheared salmon sperm DNA, followed by washing the filters in 0.1xSSC at about 65 °C. It will be recognized that a polynucleotide of the disclosure, may be operably linked to a second heterologous polynucleotide such as a promoter or a heterologous sequence encoding a desired peptide or polypeptide sequence.

[0066] Any of various art-known methods for protein purification can be used to isolate the peptides of the disclosure. For example, preparative chromatographic separations and immunological separations (such as those employing monoclonal or polyclonal antibodies) can be used. Carrier peptides can facilitate isolation of fusion proteins that include the peptides of the disclosure. Purification tags can be operably linked to a cathelicidin functional fragment of the disclosure. For example, glutathione-S-transferase (GST) allows purification with a glutathione agarose affinity column. When either Protein A or the ZZ

domain from *Staphylococcus aureus* is used as the tag, purification can be accomplished in a single step using an IgG-sepharose affinity column. The pOprF-peptide, which is the N-terminal half of the *P. aeruginosa* outer membrane protein F, can readily be purified because it is the prominent protein species in outer membrane preparations. If desired, the fusion peptides can be purified using reagents that are specifically reactive with (e.g., specifically bind) the cathelicidin functional fragment of the fusion peptide. For example, monoclonal or polyclonal antibodies that specifically bind the cathelicidin functional fragment can be used in conventional purification methods. Techniques for producing such antibodies are well known in the art.

[0067] A fusion construct comprising a peptide or polypeptide linked to a cathelicidin functional fragment of the disclosure can be linked at either the amino or carboxy terminus of the peptide. Typically, the polypeptide that is linked to the cathelicidin functional fragment is sufficiently anionic or cationic such that the charge associated with the cathelicidin functional fragment is overcome and the resulting fusion peptide has a net charge that is neutral or negative. The peptide or polypeptide linked to a peptide of the disclosure can correspond in sequence to a naturally-occurring protein or can be entirely artificial in design. Functionally, the polypeptide linked to a cathelicidin functional fragment (the "carrier polypeptide") may help stabilize the cathelicidin functional fragment and protect it from proteases, although the carrier polypeptide need not be shown to serve such a purpose. Similarly, the carrier polypeptide may facilitate transport of the fusion peptide. Examples of carrier polypeptides that can be utilized include anionic pre-pro peptides and anionic outer membrane peptides. Examples of carrier polypeptides include glutathione-S-transferase (GST), protein A of *Staphylococcus aureus*, two synthetic IgG-binding domains (ZZ) of protein A, outer membrane protein F of *Pseudomonas aeruginosa*, and the like. The disclosure is not limited to the use of these

polypeptides; others suitable carrier polypeptides are known to those skilled in the art. In another aspect, a linker moiety comprising a protease cleavage site may be operably linked to a cathelicidin functional fragment or variant of the disclosure. For example, the linker may be operable between to domains of a fusion protein (e.g., a fusion protein comprising a cathelicidin functional fragment and a carrier polypeptide). Because protease cleavage recognition sequences generally are only a few amino acids in length, the linker moiety can include the recognition sequence within flexible spacer amino acid sequences, such as GGGGS (SEQ ID NO:12). For example, a linker moiety including a cleavage recognition sequence for Adenovirus endopeptidase could have the sequence GGGGGGSMFG GAKKRSGGGG GG (SEQ ID NO:28). If desired, the spacer DNA sequence can encode a protein recognition site for cleavage of the carrier polypeptide from the cathelicidin functional fragment. Examples of such spacer DNA sequences include, but are not limited to, protease cleavage sequences, such as that for Factor Xa protease, the methionine, tryptophan and glutamic acid codon sequences, and the pre-pro defensin sequence. Factor Xa is used for proteolytic cleavage at the Factor Xa protease cleavage sequence, while chemical cleavage by cyanogen bromide treatment releases the peptide at the methionine or related codons. In addition, the fused product can be cleaved by insertion of a codon for tryptophan (cleavable by o-iodosobenzoic acid) or glutamic acid (cleavable by *Staphylococcus* protease). Insertion of such spacer digonucleotides is not a requirement for the production of cathelicidin functional fragments, such oligonucleotide can enhance the stability of the fusion polypeptide.

[0068] In one aspect of the invention, carbonate and/or peptides of the disclosure are contacted with a subject to promote/stimulate host cell defence mechanisms by, for example, stimulating epithelia to release cytokines to mount a more effective cell-mediated immune response. For example, as demonstrated in FIGs. 1-9 bicarbonate promotes LL-37 activity. In addition, FIGs. 15-16 shows the effect of LL-37 and

functional fragments on inflammatory cell recruitment and cytokine production.

[0069] The disclosure also provides a method for inhibiting the growth of a bacterium by contacting the bacterium with an inhibiting effective amount of a cathelicidin functional fragment of the disclosure. The term "contacting" refers to exposing the bacterium to a cathelicidin functional fragment peptide so that the peptide can inhibit, kill, or lyse bacteria. Contacting of an organism with a cathelicidin functional fragment of the disclosure can occur *in vitro*, for example, by adding the peptide to a bacterial culture to test for susceptibility of the bacteria to the peptide, or contacting a bacterially contaminated surface with the peptide. Alternatively, contacting can occur *in vivo*, for example by administering the peptide to a subject afflicted with a bacterial infection or susceptible to infection. *In vivo* contacting includes both parenteral as well as topical. "Inhibiting" or "inhibiting effective amount" refers to the amount of peptide that is sufficient to cause, for example, a bacteriostatic or bactericidal effect. Bacteria that can be affected by the peptides of the disclosure include both gram-negative and gram-positive bacteria. For example, bacteria that can be affected include *Staphylococcus aureus*, *Streptococcus pyogenes* (group A), *Streptococcus sp.* (viridans group), *Streptococcus agalactiae* (group B), *S. bovis*, *Streptococcus* (anaerobic species), *Streptococcus pneumoniae*, and *Enterococcus sp.*; Gram-negative cocci such as, for example, *Neisseria gonorrhoeae*, *Neisseria meningitidis*, and *Branhamella catarrhalis*; Gram-positive bacilli such as *Bacillus anthracis*, *Bacillus subtilis*, *P. acne* *Corynebacterium diphtheriae* and *Corynebacterium* species which are diptheroids (aerobic and anerobic), *Listeria monocytogenes*, *Clostridium tetani*, *Clostridium difficile*, *Escherichia coli*, *Enterobacter* species, *Proteus mirablis* and other *sp.*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Salmonella*, *Shigella*, *Serratia*, and *Campylobacter jejuni*. Infection with one or more of these bacteria can result in diseases such as

bacteremia, pneumonia, meningitis, osteomyelitis, endocarditis, sinusitis, arthritis, urinary tract infections, tetanus, gangrene, colitis, acute gastroenteritis, impetigo, acne, acne posacue, wound infections, born infections, fascitis, bronchitis, and a variety of abscesses, nosocomial infections, and opportunistic infections. The method for inhibiting the growth of bacteria can also include contacting the bacterium with the peptide in combination with one or more antibiotics.

[0070] Fungal organisms may also be affected by the cathelicidin functional fragments of the disclosure and include dermatophytes (e.g., *Microsporum canis* and other *Microsporum* sp.; and *Trichophyton* sp. such as *T. rubrum*, and *T. mentagrophytes*), yeasts (e.g., *Candida albicans*, *C. Tropicalis*, or other *Candida* species), *Saccharomyces cerevisiae*, *Torulopsis glabrata*, *Epidermophyton floccosum*, *Malassezia furfur* (*Pityrosporon orbiculare*, or *P. ovale*), *Cryptococcus neoformans*, *Aspergillus fumigatus*, *Aspergillus nidulans*, and other *Aspergillus* sp., *Zygomycetes* (e.g., *Rhizopus*, *Mucor*), *Paracoccidioides brasiliensis*, *Blastomyces dermatitides*, *Histoplasma capsulatum*, *Coccidioides immitis*, and *Sporothrix schenckii*.

[0071] A peptide(s) of the disclosure can be administered to any host, including a human or non-human animal, in an amount effective to inhibit growth of a bacterium, virus, and/or fungus. Thus, the peptides are useful as antimicrobial agents, antiviral agents, and/or antifungal agents.

[0072] Any of a variety of art-known methods can be used to administer a polypeptide or peptide to a subject. For example, the polypeptide or peptide of the disclosure can be administered parenterally by injection or by gradual infusion over time. The peptide can be administered intravenously, intraperitoneally, intramuscularly, subcutaneously, intracavity, or transdermally.

[0073] In another aspect, a cathelicidin functional fragment of the disclosure may be formulated for topical administration (e.g., as a lotion, cream, spray, gel, or

ointment). Such topical formulations are useful in treating or inhibiting microbial, fungal, and/or viral presence or infections on the eye, skin, and mucous membranes such as mouth, vagina and the like. Examples of formulations in the market place include topical lotions, creams, soaps, wipes, and the like. It may be formulated into liposomes to reduce toxicity or increase bioavailability. Other methods for delivery of the polypeptide or peptide include oral methods that entail encapsulation of the polypeptide or peptide in microspheres or proteinoids, aerosol delivery (e.g., to the lungs), or transdermal delivery (e.g., by iontophoresis or transdermal electroporation). Other methods of administration will be known to those skilled in the art.

[0074] Preparations for parenteral administration of a polypeptide or peptide of the disclosure include sterile aqueous or non-aqueous solutions, suspensions, and emulsions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oils (e.g., olive oil), and injectable organic esters such as ethyl oleate. Examples of aqueous carriers include water, saline, and buffered media, alcoholic/aqueous solutions, and emulsions or suspensions. Examples of parenteral vehicles include sodium chloride solution, Ringer's dextrose, dextrose and sodium chloride, lactated Ringer's, and fixed oils. Intravenous vehicles include fluid and nutrient replenishers, electrolyte replenishers (such as those based on Ringer's dextrose), and the like. Preservatives and other additives such as, other antimicrobial, anti-oxidants, cheating agents, inert gases and the like also can be included.

[0075] The disclosure provides a method for inhibiting a topical bacterial, viral and/or fungal-associated disorder by contacting or administering a therapeutically effective amount of a polypeptide or peptide of the disclosure to a subject who has, or is at risk of having, such a disorder. The term "inhibiting" means preventing or ameliorating a sign or symptoms of a disorder (e.g., a rash, sore, and the like). Examples of disease signs that can be ameliorated include an

increase in a subject's blood level of TNF, fever, hypotension, neutropenia, leukopenia, thrombocytopenia, disseminated intravascular coagulation, adult respiratory distress syndrome, shock, and organ failure. Examples of subjects who can be treated in the disclosure include those at risk for, or those suffering from, a toxemia, such as endotoxemia resulting from a gram-negative bacterial infection, venom poisoning, or hepatic failure. Other examples include subjects having a dermatitis as well as those having skin infections or injuries subject to infection with gram-positive or gram-negative bacteria, a virus, or a fungus. Examples of candidate subjects include those suffering from infection by *E. coli*, *Hemophilus influenza B*, *Neisseria meningitides*, staphylococci, or pneumococci. Other patients include those suffering from gunshot wounds, renal or hepatic failure, trauma, burns, immunocompromising infections (e.g., HIV infections), hematopoietic neoplasias, multiple myeloma, Castleman's disease or cardiac myxoma. Those skilled in the art of medicine can readily employ conventional criteria to identify appropriate subjects for treatment in accordance with the disclosure.

[0076] The term "therapeutically effective amount" as used herein for treatment of a subject afflicted with a disease or disorder means an amount of cathelicidin functional fragment sufficient to ameliorate a sign or symptom of the disease or disorder. For example, a therapeutically effective amount can be measured as the amount sufficient to decrease a subject's symptoms of dermatitis or rash by measuring the frequency of severity of skin sores. Typically, the subject is treated with an amount of cathelicidin functional fragment sufficient to reduce a symptom of a disease or disorder by at least 50%, 90% or 100%. Generally, the optimal dosage of the polypeptide or peptide will depend upon the disorder and factors such as the weight of the subject, the type of bacteria, virus or fungal infection, the weight, sex, and degree of symptoms. Nonetheless, suitable dosages can readily be determined by one skilled in the art. Typically, a suitable dosage is 0.5 to 40

mg peptide/kg body weight, e.g., 1 to 8 mg peptide/kg body weight.

[0077] A "viral killing amount" of antiviral is an amount sufficient to achieve a virus-killing blood concentration or a viral-killing surface concentration in or on the patient or subject receiving the treatment. In accordance with its conventional definition, an "antiviral agent," as used herein, is a chemical or biologic substance that inhibits the growth of, spread of, or kills viral particles.

[0078] If desired, a suitable therapy regime can combine administration of a polypeptide or peptide of the disclosure with one or more additional therapeutic agents (e.g., an inhibitor of TNF, an antibiotic, and the like). The peptide(s), other therapeutic agents, and/or antibiotic(s) can be administered, simultaneously, but may also be administered sequentially. Suitable antibiotics include aminoglycosides (e.g., gentamicin), beta-lactams (e.g., penicillins and cephalosporins), quinolones (e.g., ciprofloxacin), and novobiocin. In addition, the N-terminal cathelin-like fragment of SEQ ID NO:6 has antibacterial activity.

Accordingly, a combination of the N-terminal fragment of SEQ ID NO:6 comprising the cathelin-like domain (e.g., SEQ ID NO:6 from about amino acid 31 to amino acid 131) and the C-terminal domain comprising a cathelicidin functional fragment can be co-administered or administered sequentially. Generally, the antibiotic is administered in a bactericidal, antiviral and/or antifungal amount. The peptide provides for a method of increasing antibiotic activity by permeabilizing the bacterial outer membrane and combinations involving peptide and a sub-inhibitory amount (e.g., an amount lower than the bactericidal amount) of antibiotic can be administered. Typically, the cathelicidin functional fragment and antibiotic are administered within 48 hours of each other (e.g., 2-8 hours, or may be administered simultaneously). A "bactericidal amount" is an amount sufficient to achieve a bacteria-killing blood concentration in the subject receiving the treatment. In accordance with its conventional definition, an

"antibiotic," as used herein, is a chemical substance that, in dilute solutions, inhibits the growth of, or kills microorganisms. Also encompassed by this term are synthetic antibiotics (e.g., analogs) known in the art.

[0079] The polypeptides or peptides of the disclosure can be used, for example, as preservatives or sterillants of materials susceptible to microbial or viral contamination. For example, the peptides can be used as preservatives in processed foods (e.g., to inhibit organisms such as *Salmonella*, *Yersinia*, and *Shigella*). If desired, the peptides can be used in combination with antibacterial food additives, such as lysozymes. The peptides of the disclosure can also be used as a topical agent, for example, to inhibit *Pseudomonas* or *Streptococcus* or kill odor-producing microbes (e.g., *Micrococci*). The optimal amount of a cathelicidin functional fragment of the disclosure for any given application can be readily determined by one of skill in the art.

[0080] The cathelicidin functional fragments of the disclosure are also useful in promoting wound repair and tissue regeneration. Matrix metalloproteinases (MMPs) are inflammatory enzymes that degrade proteins in various tissues. Recent scientific research has shown elevated levels of proteases (e.g., MMPs) in chronic wound exudate, the fluid that bathes the wound bed. These excess proteases cause degradation of important extracellular matrix proteins and inactivation of vital growth factors that are essential in the wound healing process. This may contribute to a sub-optimal healing environment resulting in delayed wound healing.

[0081] The cathelicidin functional fragments of the disclosure can be used to treat damaged tissue, such as wounds (in particular chronic wounds), more effectively. As demonstrated herein, the cathelicidin functional fragments of the disclosure are effective protease inhibitors. The cathelicidin functional fragments of the disclosure are capable of inhibiting the action of specific proteins that are upregulated in a wound environment wherein those proteins have an adverse effect in the wound environment. Typically the

adverse effect is a deleterious effect on wound healing. Hence, the cathelicidin functional fragments of the disclosure can be used to inhibit the deleterious effects of proteases that are upregulated in a wound environment. Simultaneously, the cathelicidin functional fragments of the disclosure also are capable of serving as antibacterial agents that reduce the risk of infection at a wound site by inhibiting proteases produced by pathogens in the wound site.

[0082] Intracellular mature virions (IMV) of vaccinia have a double layer membrane of endoplasmic reticulum derived membrane cisternae. As the IMV migrates through an infected cell the virion acquires a double layer outer envelope consisting of a cellular cisternae known as a wrapping membrane and become intracellular enveloped virions. Egress from the cell is accompanied by fusion of the outermost layer with the plasma membrane yielding a three layer outer membrane on extra-cellular enveloped virions (EEV). Both the IMV and EEV forms are infectious with the EEV being most efficient in cell entry. The disclosure demonstrates that cathelicidin functional fragments, related homologues, and variants thereof, are effective at disrupting the IMV and EEV of the virions thus being useful as antiviral agents.

[0083] The disclosure includes the use of cathelicidin functional fragments for treatment of viral skin disease, especially for the treatment of vaccinia and small pox infection. As the molecules are proteins, they are most well suited for topical application. However, peptidomimetics and other protein analogs with more favorable pharmacokinetic and pharmacodynamic properties can be developed for use with other routes of administration including, but not limited to, oral and parenteral. The compounds can be incorporated into appropriate delivery devices dependent upon the route of administration and other considerations well known to those skilled in the art. Additionally as cathelicidin functional fragments are peptides, the coding sequence could be delivered to the site of interest using any gene transfer protocol to allow for expression of the gene product.

[0084] The cathelicidin functional fragments can be used in conjunction with vaccination to ameliorate or prevent eczema vaccination or after vaccination for the treatment of skin conditions. The cathelicidins can also be used for infections developed due to infection from other sources.

[0085] The disclosure provides cathelicidin functional fragments which have antiviral activity. The cathelicidin functional fragments are useful for inhibiting viral infection or spread, as well reducing the effects of viral infection. One or more cathelicidin functional fragment peptides can be used, for example, as an antiviral agent in topical lotions as well as in other pharmaceuticals including soaps and wipes. A cathelicidin functional peptide fragment of the disclosure can be used alone or in combination with conventional antiviral agents and can be used as an adjunct therapy.

[0086] Resolution of infection and protection against re-infection with viruses depends on cooperation between innate and adaptive immune processes. These processes include anti-viral proteins, complement activation, macrophages, NK, numerous cytokines, cytotoxic T cells, specific antibodies and γ/δ T cells. In addition to the alteration in the skin barrier in atopic dermatitis (AD), alterations in cellular immunity have been described in this disease. These alterations are possible candidate mechanisms for the serious consequences of herpes viruses and vaccinia virus in this skin disease. Goodyear et al. had previously observed increased quantities of HSV when cultured on skin explants obtained from patients with AD and psoriasis compared to skin from normal individuals (Clin. Exp. Dermatol. 21:185, 1996). These experimental conditions were performed in the absence of many of these defense mechanisms. Eczema vaccinatum is a complication of smallpox vaccination seen within ten days after virus inoculation during primary immunization, also suggesting an important role for local, innate immune responses in restricting vaccinia viral replication.

[0087] The effect of cathelicidin functional fragments on vaccinia virus have not been reported. The mechanism of action

for these peptides is hypothesized to involve disruption of the microbial membrane and/or the penetration of the microbial membranes to interfere with intracellular functions.

Keratinocytes are primary producers of cathelicidin and LL-37 in the skin following injury or an inflammatory skin response. The disclosure demonstrates the effect of cathelicidins functional fragments on vaccinia virus replication *in vitro*.

[0088] *Eczema Vaccinatum* (EV) is one of the major complications of small pox vaccination and occurs in patients with a history of atopic dermatitis (AD), a Th2-mediated skin disease. Recently it was found that AD skin is deficient in its ability to express certain endogenous antimicrobial peptides, also known as cathelicidins, such as LL-37 (Ong et al., NEJM 2002; 347:1151-60). This group of patients is known to be much more susceptible to serious complications of infection with vaccinia and related viruses. Vaccinia virus is used for small pox vaccination.

[0089] The term "purified" or "substantially purified" as used herein refers to a peptide that is substantially free of other proteins, lipids, and nucleic acids (e.g., cellular components with which an *in vivo*-produced peptide would naturally be associated). Typically, the peptide is at least 70%, 80%, 90%, or more pure by weight.

[0090] The disclosure also provides a method for inhibiting the spread or infection of a virus by contacting the virus or a surface upon which a virus may be present with an inhibiting effective amount of a cathelicidin functional fragment peptide of the disclosure. The term "contacting" refers to exposing the virus to a cationic antiviral peptide so that the peptide can inhibit the spread of infectivity of a virus or kill the virus itself. For example, by adding a cathelicidin functional fragment to a culture comprising a virus (e.g., vaccinia virus) one can measure the susceptibility of a culture to the infectivity of a virus in the presence and absence of a cathelicidin functional fragment. Alternatively, contacting can occur *in vivo*, for example, by administering a cathelicidin functional fragment to a subject that is

susceptible to or afflicted with a viral infection. The administration includes topical as well as parenteral. "Inhibiting" or "inhibiting effective amount" refers to the amount of a peptide that is sufficient to cause a viral inhibition or kill a virus. Examples of viruses that can be inhibited include herpesviridae (herpes simplex virus (HSV), varicella-zoster virus), vaccinia virus, Pappiloma virus and other viruses causing skin diseases. The method for inhibiting the viral infection can also include the contacting of a virus with a cathelicidin functional fragment alone or in combination with one or more other antiviral agents.

[0091] The cathelicidin functional fragments are also useful as a broad-spectrum antimicrobials suitable for tackling the growing problem of antibiotic-resistant bacteria strains, and for treating and/or preventing outbreaks of infectious diseases, including diseases caused by bioterrorism agents like anthrax, plague, cholera, gastroenteritis, multidrug-resistant tuberculosis (MDR TB). The cathelicidin functional fragments, kits, and carbonate preparations of the disclosure can be used therapeutically and prophylactically for biodefense against new bioattacks. For example, the disclosure provides kits containing formulations comprising a cathelicidin functional fragment of the disclosure and/or carbonate formulations. The kits can be provided, for example, to a population subject to bioterrorist attacks (e.g., the military). The carbonate preparations can be applied/administered either before (prophylactic) during or after exposure to a pathogenic viral organism, bacteria, fungus, or mutant strains thereof, to induce a subject's natural LL-37/cathelicidin activity. Alternatively, the subject can apply/administer a cathelicidin functional fragment either alone or in combination with a formulation comprising a carbonate agent.

[0092] A cathelicidin functional fragment(s) of the disclosure can be administered to any host, including a human or non-human animal, in an amount effective to inhibit growth of a virus, bacterial or fungus.

[0093] In another aspect, the invention provides methods and compositions useful to treat microbial, viral, and/or fungal infections comprising contacting or administering to a subject at risk of or having an infection a carbonate composition that modulates the activity of LL-37 or cathelicidin functional fragments.

[0094] Any of a variety of art-known methods can be used to administer a cathelicidin functional fragment and/or a carbonate composition to a subject. For example, a composition of the disclosure can be administered parenterally by injection or by gradual infusion over time. The peptide can be administered intravenously, intraperitoneally, intramuscularly, subcutaneously, intracavity, or transdermally. In another aspect, a composition of the disclosure may be formulated for topical administration (e.g., as a lotion, cream, spray, gel, or ointment). Examples of formulations in the market place include topical lotions, creams, soaps, wipes, and the like. It may be formulated into liposomes to reduce toxicity or increase bioavailability. Other methods for delivery of the peptide include oral methods that entail encapsulation of the peptide in microspheres or proteinoids, aerosol delivery (e.g., to the lungs), or transdermal delivery (e.g., by iontophoresis or transdermal electroporation). Other methods of administration will be known to those skilled in the art.

[0095] Preparations for parenteral administration of a peptide of the disclosure include sterile aqueous or non-aqueous solutions, suspensions, and emulsions. Examples of non-aqueous solvents are propylene glycol, polyethylene glycol, vegetable oils (e.g., olive oil), and injectable organic esters such as ethyl oleate. Examples of aqueous carriers include water, saline, and buffered media, alcoholic/aqueous solutions, and emulsions or suspensions. Examples of parenteral vehicles include sodium chloride solution, Ringer's dextrose, dextrose and sodium chloride, lactated Ringer's, and fixed oils. Intravenous vehicles include fluid and nutrient replenishers, electrolyte

replenishers (such as those based on Ringer's dextrose), and the like. Preservatives and other additives such as, other antiviral agents, anti-oxidants, cheating agents, inert gases and the like also can be included.

[0096] The disclosure provides a method for inhibiting viral infection and spread of such viruses as herpesviridae (herpes simplex virus (HSV), varicella-zoster virus), vaccinia virus, Pappiloma virus and other viruses causing skin diseases, as well as diseases and disorders associated with atopic dermatitis by administering a therapeutically effective amount of a cathelicidin functional fragment of the disclosure to a subject who has, or is at risk of having, such an infection or disorder. The term "inhibiting" means preventing or ameliorating infectivity of a virus or a sign or symptoms of a disorder (e.g., atopic dermatitis). Examples of disease signs that can be ameliorated include skin sores and lesions associated with herpesviridae (herpes simplex virus (HSV), varicella-zoster virus), vaccinia virus, Pappiloma virus and other viruses causing skin infection such as those seen in atopic dermatitis. Examples of patients who can be treated in the disclosure include those at risk for, or those suffering from, a viral infection, such as those resulting from Herpesviridae (herpes simplex virus (HSV), varicella-zoster virus), vaccinia virus, Pappiloma virus and other viruses causing skin diseases. Those skilled in the art of medicine can readily employ conventional criteria to identify appropriate subjects for treatment in accordance with the disclosure.

[0097] The cathelicidin functional fragment of the disclosure can be used, for example, as preservatives or sterillants of materials susceptible to viral contamination. For example, the peptides can be used as preservatives in processed foods, as spray disinfectants commonly used in the household or clinical environment. The optimal amount of a cationic peptide of the disclosure for any given application can be readily determined by one of skill in the art.

[00098] In another aspect, the disclosure provides knockout non-human animals that are useful to screen potential antiviral and antibacterial cathelicidin functional fragments and agents useful for treating such diseases and disorders as atopic dermatitis.

[00099] As a model to study the potential *in vivo* significance of LL-37 deficiency, CRAMP Cnlp knockout mice known to lack expression of CRAMP, a close murine ortholog of cathelicidin human LL-37, were developed and used. Importantly these mice generated a significantly greater number of pox skin lesions than seen in wild type isogenic control mice. The two mice that did not generate pox skin lesions died within two days of septic shock following smallpox vaccination.

[00100] These *in vitro* and *in vivo* observations suggest that the increased susceptibility of atopic dermatitis patients to eczema vaccinatum may be due to a deficiency of cathelicidin. Such knockout mice are effective models to test the therapeutic effects of cathelicidin functional fragments.

[00101] The following examples are intended to illustrate but not limit the disclosure. While they are typical of those that might be used, other procedures known to those skilled in the art may alternatively be used.

EXAMPLES

Materials and Methods

[00102] Sweat collection and processing. Sweat was collected on paper tissues (Kimwipes, Kimberly-Clark, GA) from healthy volunteers after exercise. After collection, 20 ml of sweat was centrifuged at 2000g for 15 min. at 4°C, filtered through a 0.20 ml filter (Acrodisc syringe filter, 0.2 mm, low protein binding, Fisher scientific, Tustin, CA), and frozen at -80°C. For some experiments sweat was lyophilized to dryness, then suspended in 400 µl of distilled water (DW: cell culture grade, endotoxin free, GibcoBRL, Grand island, NY). For analysis of LL37 processing by sweat, 1.6 nmol of LL-37 synthetic peptide was incubated in 50 ml of sweat for 0, 1, 6, 24 hrs at 37°C or 4°C. In some experiments proteinase

inhibitors including; mixed protease inhibitor cocktail (1tab/10ml, Roche, Indianapolis, IN), 100 mg/ml Bestatin, 10 mg/ml E-64, 10 mg/ml Aprotinin, (Sigma, St Louis, MO); 100 mM AEBSF, 100 mM Neutrophil elastase inhibitor (NEI) or 100 mM leukocyte elastase inhibitor (LEI) (Calbiochem, San Diego, CA) were added during incubation. After incubation, 2 ml was assayed by radial diffusion assay to determine antibacterial activity. For analysis by HPLC 32 nmoles LL-37 was incubated in 100ul. To control for potential contamination from paper tissues, parallel processing was done on tissues soaked in phosphate-buffered saline (PBS:137 mM NaCl, 2.7 mM KCL, 4.3 mM Na₂HPO₄-H₂O, 1.4 mM KH₂PO₄, pH 7.4). No antimicrobial activity was detectable in these preparations. Protein concentrations were evaluated by BCA assay (protein assay reagent, Pierce, Rockford, IL) or Bradford protein assay (Bio-Rad, Hercules, CA) according to manufacture's instructions. Human tissue and blood collection was approved by the UCSD Human Research Protection Program.

[00103] *Peptide synthesis.* Dermcidin, LL-37, RK-31, KS-30, and KR-20 peptides were commercially prepared by Synpep Corporation, Dublin, OR. Peptide amino acid sequences were LLGDDFFRKSKEKIGKEFKRIVQRIKDFLRNLPRTES (LL-37), RKSKEKIGKEFKRIVQRIKDFLRNLPRTES (RK-31), KSKEKIGKEFKRIVQRIKDFLRNLPRTES (KS-30), KRIVQRIKDFLRNLPRTES (KR-20), SSSLLEKGLDGAKKAVGGGLGKLGKDAVEDLESVGKGAVHDVKDVLDSV (dermcidin). All 5 synthetic peptides were purified by HPLC and identity confirmed by mass spectrometry.

[00104] *HPLC chromatography.* Peptide separation was performed using an AKTA purification system (Amersham Pharmacia Biotech, Piscataway, NJ) on a Sephasil peptide C18 column (12 mm, ST 4.6/250, Amersham Pharmacia Biotech, Piscataway, NJ). Concentrated human sweat, or LL-37 incubated in sweat, was separated by reversed phase (RP- HPLC) following column equilibration in 0.1% TFA at a flow rate of 0.5 ml/ml and eluted using gradients of 0-35% and 35-60% acetonitrile for 16 min, 67 min, or 0-60% acetonitrile for 120 min. Column effluent was monitored at 214, 230, and 280nm. All collected

fractions (1 ml) were lyophilized and suspended in 10 ml of DW for antimicrobial radial diffusion assay.

[00105] *Western and Immunoblot analysis.* Fractions purified by HPLC as described above were evaluated by quantitative dot-blot and Western Blot. 2 μ l of each fraction was compared to a standard curve of synthetic LL37 peptide applied onto PVDF membrane (Immobilon-P, Millipore, MA). Antibody used was rabbit anti-LL-37 polyclonal antibody derived and affinity purified against the entire LL-37 peptide. For immunoblot, membranes were blocked (0.1% TTBS: 5% nonfat milk in 0.1% Tween 20/tris buffered saline (TBS: 150 mM NaCl, 10 mM Tris Base, pH 7.4)) for 60 min at room temperature, and then rabbit anti LL37 polyclonal antibody (1:5000 in blocking solution) was incubated with the membrane overnight at 4°C. After washing 3x with 0.1% TTBS, horseradish peroxidase labeled goat anti rabbit antibody (1:5000 in the blocking solution, (DAKO, CA) was incubated with the membrane for 60 min, room temperature. After washing the membrane again with 0.1% TTBS, the membrane was immersed in ECL solution (Western Lightning Chemiluminescence Reagents Plus, New Lifescience Products, Boston, MA) for 60 sec then exposed to X-ray film (Kodak). For, Western-blot analysis, sweat samples (10 μ l) were separated by 16.5% tris/tricine/peptide gel (BIO-RAD, Hercules, CA), and then transferred on to a PVDF membrane (Immobilon-P, Millipore, MA). For positive control, 5 pmol LL-37 synthetic peptide was applied.

[00106] *Mass spectrometry and Protein sequence analysis.* Mass spectrometry was performed by Center for Mass Spectrometry, The Scripps Research Institute (La Jolla, CA). MALDI-MS spectra were obtained with a Voyager DE-RP MALDI-TOF mass spectrometer (PerSeptive Biosystems, Framingham, MA) equipped with a nitrogen laser (337 nm, 3-ns pulse). Spectra were collected in reflector mode. The accelerating voltage in the ion source was 20 kV. Data were acquired with a transient recorder with 2-ns resolution. The matrix used in this work was -cyano-4-hydroxycinnamic acid dissolved in water/acetonitrile (1:1, v/v) to give a saturated solution at

room temperature. To prepare the sample for analysis, 1 μ l of the peptide solution (containing 1-10 pmol of protein in 0.1% trifluoroacetic acid) was added to 1 μ l of the matrix solution and applied to a stainless steel sample plate. The mixture was then allowed to air dry on the sample plate before being introduced into the mass spectrometer. Each spectrum was produced by accumulating data using 128 laser pulses. Mass assignments were assigned with an accuracy of approximately $\pm 0.1\%$ (± 1 Da/1000 Da). Protein sequence analysis for target HPLC fractions was performed by Division of Biology Protein Sequencer Facility, University of California, San Diego.

[00107] The amino acid sequencing was performed on an Applied Biosystems Procise Model 494 sequencer using the "pulsed-liquid" program supplied by the manufacture.

[00108] *Antimicrobial assays.* For screening of antimicrobial activity of HPLC fractions, radial diffusion assay was used. Lyophilized HPLC fractions were dissolved in DW (GibcoBRL, Grand Island, NY), and tested against *Staphylococcus aureus mprF*. Thin plates (1 mm) of 1% agarose in 0.5% tryptone containing approximately 1×10^6 cells/ml of *S. aureus mprF* were used. 1 mm wells were punched in the plates and 2ml of samples dissolved in tissue culture grade sterile water were loaded in each well.

[00109] As a positive control, synthetic LL-37 was applied to separate wells. After incubation at 37 °C overnight, the inhibition zones were recorded by CCD camera and diameters measured. To evaluate antimicrobial activity against wild-type *S. aureus* (clinical isolate), and enteroinvasive *E.coli* O29, both radial diffusion and solution killing assays were done. Radial diffusion assays were done as described for *S.aureus mprF*. Solution killing was done in 10%TSB in 10mM PB (TSB=30gm/L Tryptic Soy Broth, Sigma, St Louis MO; 20X PB= 27.6 g/L $\text{NaH}_2\text{PO}_4\text{-H}_2\text{O}$, 53.65 g/L $\text{Na}_2\text{HPO}_4\text{-7H}_2\text{O}$, pH 7.4). Bacteria in log-phase growth were suspended to 1×10^6 cells/ml, peptide added and incubated at 37°C for 2 hr. Bacteria were then plated on TSB agar (TSB, Bactoagar 13g/L, Becton

Dickinson, Sparks MD) for direct colony count and determination of CFU.

[00110] Activity against Group A Streptococcus (NZ131) was done only in solution assay as described. To evaluate antimicrobial activity in high salt conditions, solution assay was done in 10%TSB/10mM PBS with several salt concentrations (concentration of NaCl; 10, 50, 100, 150, 300, 500 mM). Action against the *C. albicans* was determined in Dixon medium (0.6% Peptone, 4% Malt Extract, 1% Glucose, 0.1% Ox Bile, 1% Tween-80) in sterile 96-well microtiter plates (Corning Inc., Corning, NY) at a final volume of 50 ml. The assay mixtures contained $1-2.5 \times 10^4$ PFU/ml freshly grown *Candida*, 20% Dixon medium, 0.6mM phosphate buffer pH 7, and 16 mg/ml chloramphenicol. Microtiter plates were incubated at 37°C for 24h with peptides, then plated on Dixon agar to determine the MFC (minimum fungicide concentration).

[00111] *Hemolysis Assay*. Hemolytic activity was determined on human whole blood. Freshly obtained whole blood was washed 3X in PBS and resuspended in PBS at its original volume containing peptides at indicated concentrations. Samples were incubated at 37 °C for 1.5 to 3 h, and hemolysis determined by centrifuging at 300g and measurement of the absorbance of the supernatant at 578 nm. Hemolytic activity of each peptide was expressed as the percentage of total hemoglobin released compared to that released by incubating with 0.1% Triton X-100.

[00112] *Measurement of IL-8 release from keratinocytes*
Normal human keratinocytes (NHK) were cultured in EpiLife cell medium (Cascade Biologics, Portland, OR) containing 0.06 mM Ca²⁺, 1x EpiLife-defined growth supplement (EDGS), 50 U/ml penicillin and 50 mg/ml streptomycin (Invitrogen, Carlsbad, CA). Keratinocytes were seeded in a 96-well plate and grown to confluence under standard tissue culture conditions. Cells were incubated with 3mM or 10mM LL-37 or LL37-derived peptides (e.g., cathelicidin functional fragments) for 8 hours at 37°C. Supernatants were collected and stored at -20°C overnight. IL-8 ELISA Assay was performed according to the manufacturer's

instructions (BD OptEIA, Pharmingen, San Diego, CA). Supernatants were diluted 1:10 for assay. Simultaneously, LDH assays (Roche, Indianapolis, IN) were used to assess the cytotoxicity of peptides to keratinocytes. LDH release following peptide exposure was compared to release induced by 1% Triton X100.

Results

[00113] To identify antimicrobial activity present at the skin surface, human sweat was collected from normal volunteers, concentrated, and separated by high performance liquid chromatography (HPLC). Fractions of the material eluted between 35-65% acetonitrile were individually evaluated for the ability to inhibit the growth of *S. aureus mprF* by radial diffusion assay (Figure 10). Multiple distinct fractions were found to be active in this assay. Prior evaluations of human sweat have shown that the antimicrobial peptides LL-37 and dermcidin are produced by the eccrine apparatus and secreted into the topical soluble environment of sweat. As expected, these molecules were detectable in the sweat preparation shown in Figure 10. The presence of LL-37 was confirmed by immunoblot analysis with antibody specific to LL-37 and by MALDI-TOF mass spectrometry. The dermcidin peptides, DCD and DCD-1L, were identified by MALDI-TOF mass spectrometry and N-terminal amino acid sequencing.

[00114] Immunoblot analysis with anti-LL-37 antibody of all fractions isolated by HPLC from the human sweat suggested that other molecules related to LL-37 may be present in fractions eluting between 43 and 48% acetonitrile. These fractions were associated with antimicrobial activity but not identifiable by MALDI-TOF mass spectrometry and N-terminal amino acid sequencing from the concentrated sweat preparations. Based on the immunoreactivity and elution profile we hypothesized that these antimicrobial molecules were alternative forms of LL-37 that were further processed in sweat to unique cathelicidin peptides. To test this, human sweat was freshly collected, sterilely filtered, then synthetic LL-37 added to a final concentration of 32 mM. The relative ability of this solution

to inhibit the growth of *S. aureus mprF* was then evaluated. Following incubation at 37°C in sweat, LL-37 increased the zone of inhibition and apparent antimicrobial activity (Figure 11a). Incubation of LL-37 under identical conditions in PBS or distilled water did not affect activity. This increase in apparent antimicrobial activity did not occur at 4°C and was inhibited by the addition of protease inhibitor cocktail, thus suggesting the gain in antimicrobial function was a consequence of an enzymatic process (Figure 11b). Addition of specific inhibitors of potential processing enzymes demonstrated that the serine protease inhibitors AEBSF and Aprotinin were most effective in blocking the increase in antimicrobial activity generated by incubation of LL-37 in sweat (Figure 11c).

[00115] An increase in the relative ability of LL-37 to inhibit growth of *S. aureus mprF* suggested that the enzymatic processing of this peptide resulted in alternative forms with either increased direct antimicrobial activity or an ability to synergize with the parent peptide. To identify these processed forms of LL-37, synthetic peptide was incubated with the sterile sweat preparation and separated by HPLC after various periods of incubation (Figure 12a). An increase in the relative abundance of several proteins was seen over time.

[00116] Correlation of this profile with antimicrobial activity showed fractions eluting at 39% and 48% acetonitrile gained antimicrobial activity coincident with an increase in relative abundance of peptides eluting at these positions (Figure 12b). A third major peak of antimicrobial activity seen between 53 and 56% acetonitrile showed a relative decrease in abundance as estimated by absorbance at 214 nm. MALDI-TOF mass spectrometry and N-terminal sequencing of the peptide eluting at 39% acetonitrile identified this as a 20 amino acid cathelicidin derivative, KR-20 (Figure 13a). Similar analysis of peptides eluting at 48% acetonitrile identified two additional cathelicidin peptides RK-31 and KS-30 (Figure 13b). Western blot analysis with antibody against LL-37 confirmed antigenic similarity of RK-31 and KS-30 to parent

LL-37 (Figure 13c). KR-20 was not detectable with this antibody. Material eluting at 55-56% acetonitrile and decreasing in abundance with incubation was identified as LL-37 by both Western blot and Mass spec analysis (Figure 13c and d).

[00117] The newly described human cathelicidin peptides KR-20, RK-31 and KS-30 eluted at positions corresponding to unidentified antimicrobial activity seen in crude sweat preparations partially purified in Figure 10. The low relative abundance of these peptides, yet easily detectable antimicrobial activity suggested that these peptides might gain antimicrobial activity with processing when compared to LL-37. To compare the antimicrobial activity of these cathelicidins, purified synthetic peptides corresponding to LL-37, RK-31, KS-30 and KR-20 were assessed by both radial diffusion assay and solution assay against a variety of microbes (Figure 14). RK-31 and KS-30 showed greatly increased action against wild-type *S. aureus* and *E. coli*. And all three new peptides showed increased fungicidal activity against *Candida albicans*. Furthermore, these peptides were synergistic, killing bacteria at lower concentrations when present together, (Figure 14d), and maintained activity at increased salt conditions (Figure 14e,f). Hemolytic activity against human erythrocytes was minimal as seen by assay at a concentration 5 to 10 times greater than that required for antimicrobial activity (Table 2).

Table 2. Antimicrobial and hemolytic activity of human sweat peptides.

Radial Diffusion Assay (μm)				Liquid Assay (μm)		
	<i>S. aureus</i> MprF	<i>S. aureus</i> (wt)	<i>E. coli</i> (O29)	GAS (NZ131)	<i>C. albicans</i> ATCC 14053	% hemolysis
LL-37	32	>64	64	8	20	9
RK-31	8	16	8	8	4	6
KS-30	8	16	8	4	2	.23
KR-20	16	>64	>64	4	10	0
DCD	>64	>64	>64	>64	>32	nd

Radial diffusion assay results represent minimal inhibitory concentrations (MIC) determined for peptides against indicated bacteria. Liquid assay results represent minimal concentration required to kill Group A Streptococcus (GAS) or *Candida albicans*. Percent hemolysis is shown for peptides at the following

concentrations: LL-37 and KR-20 = 100 μ M; RK-31 = 44 μ M; KS-30 = 88 μ M. nd=not done.

[00118] However, despite gaining antimicrobial activity by processing to shorter forms of the cathelicidin peptide, hemolytic activity of these antimicrobials decreased relative to LL-37.

[00119] In addition to the function of antimicrobial peptides as natural antibiotics, many of these molecules have been associated with the ability to stimulate a variety of host responses. To determine if the secretion and processing of cathelicidin peptides at the surface of the skin could also stimulate a host inflammatory response, human keratinocytes were grown in culture and assayed for the release of IL-8 in response to these peptides. All peptide solutions were endotoxin free. LL-37 had a potent ability to stimulate IL-8 release from keratinocytes, but processing to the shorter form of these cathelicidins decreased the ability to stimulate IL-8 (Figure 15). Cellular toxicity of these peptides was simultaneously evaluated by determination of the release of lactate dehydrogenase into keratinocyte culture medium. At a concentration of 3 mM none of the peptides evaluated significantly increased the permeability of keratinocyte membranes.

[00120] LL-37 was demonstrated to bind FPRL-1, induces neutrophil and mast cell chemotaxis (see, e.g., FIG. 16). LL-37 blocks pro-inflammatory chemokine release from dendritic cells, but induces pro-inflammatory release from keratinocytes. CRAMP has similar effect in mouse dendritic cells (FIG. 17) and inhibits antigen presentation *in vitro* (FIG. 18A-C). This effect is dissociated from cathelicidin functional fragments.

[00121] FIG. 19A-C shows the identification of cathelicidin function fragments on the normal skin surface by HPLC. FIG. 20 shows a schematic of cathelicidin processing on the normal skin surface.

[00122] A number of embodiments of the invention have been described. Nevertheless, it will be understood that various

modifications may be made without departing from the spirit and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.